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Automation for Reduced Manning (DC-ARM) Intelligent Controller — Part 1

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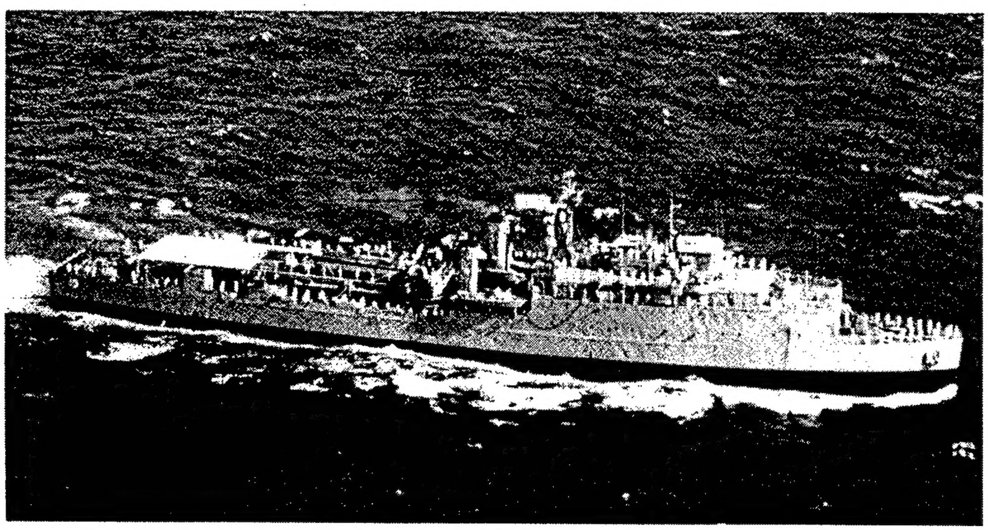

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13. ABSTRACT (*Maximum 200 words*)

This report documents the achievements of the first-year's effort in a four-year research and development program to develop autonomous control technology for application to shipboard damage assessment and control for reduced manning (DC-ARM). A prototype intelligent controller (IC) was designed for application to a single compartment. This prototype was successfully demonstrated in a laboratory model of a compartment that incorporated COTS sensors and actuators. The compartment model and IC are described and results are discussed. Identification of issues to be addressed and proposed follow-on tasks are included.

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EXECUTIVE SUMMARY

In the sweeping period of increased military material and personnel cost, the U.S. Navy desires to identify means of reducing ship life cycle cost through identification of automated systems that will replace the large number of personnel currently dedicated to damage control. The Intelligent Controller (IC), previously proven in production weapon automation, is considered a leading candidate in support of the required automated capability that will eventually provide for reduced manning. The Applied Research Laboratory (ARL) of Pennsylvania State University (PSU), under a Naval Research Laboratory contract, and working under the technical and operational guidance of Ship Survivability Technologies, was the primary IC prototype contractor.

The project objective was to demonstrate a supervisory autonomous control capability for damage assessment and control that would facilitate manning reduction. The contracted tasks were, (1) Casualty Characterization, (2) Situation Assessment, (3) Automated Casualty Response and (4) Systems Integration and Test. At the conclusion of the contract a demonstration was required to provide proof of concept of the IC-driven automated response to fire, smoke and flooding.

The IC was developed in a manner that provided for analysis and response through use of commercial off-the-shelf (COTS) sensors, and systems actuators that operated appropriate casualty controlling systems. A prototype PC-supported IC system was developed in conjunction with a transparent model of a ship's compartment, which allowed viewing of the damage control activities. The contract concluded with a satisfactory proof of concept demonstration of IC-generated responses that controlled fires, smoke evacuation and flooding.

AUTOMATION FOR REDUCED MANNING (DC-ARM) INTELLIGENT CONTROLLER – PART 1

1. INTRODUCTION

Due to increased military material and personnel cost, the U.S. Navy is in the process identifying means of reducing life cycle cost through automated systems that replace the damage control labor intensive personnel requirements. This DC-ARM research and development project is a preliminary effort to assess and determine the viability of developing automated systems to reduce the number of ship's crews dedicated to damage control.

The conduct of research and development supporting the Intelligent Controller proof of concept was achieved under NRL Contract No. N00014-97-C-2074 that prescribed four tasks with specific elements involving the automated IC system. The primary contract management and technical direction was assigned to Robert Barr of Ship Survivability Technologies (SST), Triangle, VA. The R&D project was achieved solely by Penn State ARL, State College, PA.

The primary contract requirement was a product demonstration to be conducted in the later phase of the period. This demonstration was achieved through utilization of a prototype Intelligent Controller described later in this report.

2. PROJECT OBJECTIVE

The objective of this project is to develop and demonstrate a supervisory autonomous control capability for damage assessment and control to facilitate reduction of damage control personnel manning. The autonomous control system should be able to identify the existence of casualties such as fire, smoke, and flooding and react appropriately by issuing command signals to actuators such as fire-suppression systems or ventilators. The IC system must also be able to work in collaboration with a human monitor.

3. TECHNICAL APPROACH

The approach was to progress from near-term (first year) demonstrations to improved sensing and automated reasoning in a laboratory PC-based environment; then to an integrated sensing/assessment/control capability demonstrated in land-based test beds; to the ultimate "full-up" demonstrations and tests in situ on-board ship. The intent is to accomplish the required four-task effort within an integrated damage control automated systems architecture.

Four integrated tasks were addressed to demonstrate the feasibility of advanced sensing, information integration and transfer, and automated reasoning response. See Figure 1 "Automated Damage Assessment and Casualty Response". The following is a brief description of each task.

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3.1 *Task 1 - Characterization of Ship Casualty*

Improvements in the ability to characterize a casualty and current status of the ship structures (e.g., damage due to fire, flooding and structural damage), will be achieved by implementation of new sensors and on-line monitoring systems. In the first year, existing commercial off-the-shelf (COTS) sensors were used in the automated control system demonstration. Studies were made which determined availability and characteristics of advanced sensors such as those based on MEMS technology. Discussions and meetings were held with groups working in this field. The conclusion was that research is being conducted to develop advanced sensing systems, but that it is not presently clear what sensors will be available and practical for application to ship automation beyond the base sensor suite currently deployed on the ex-USS SHADWELL [1].

3.2 *Task 2 - Situation Awareness (Assessment)*

This task is to develop an automated capability supporting awareness of the current situation in ship's compartments by analyzing and integrating sensor information. A new approach to such automatic recognition of environmental features was applied, based on a new fuzzy-logic modeling developed by Penn State ARL for application to autonomous systems. This task falls under the scope of supervisory control system (SCS) development. Achievements under this task are discussed in the Intelligent Controller section below.

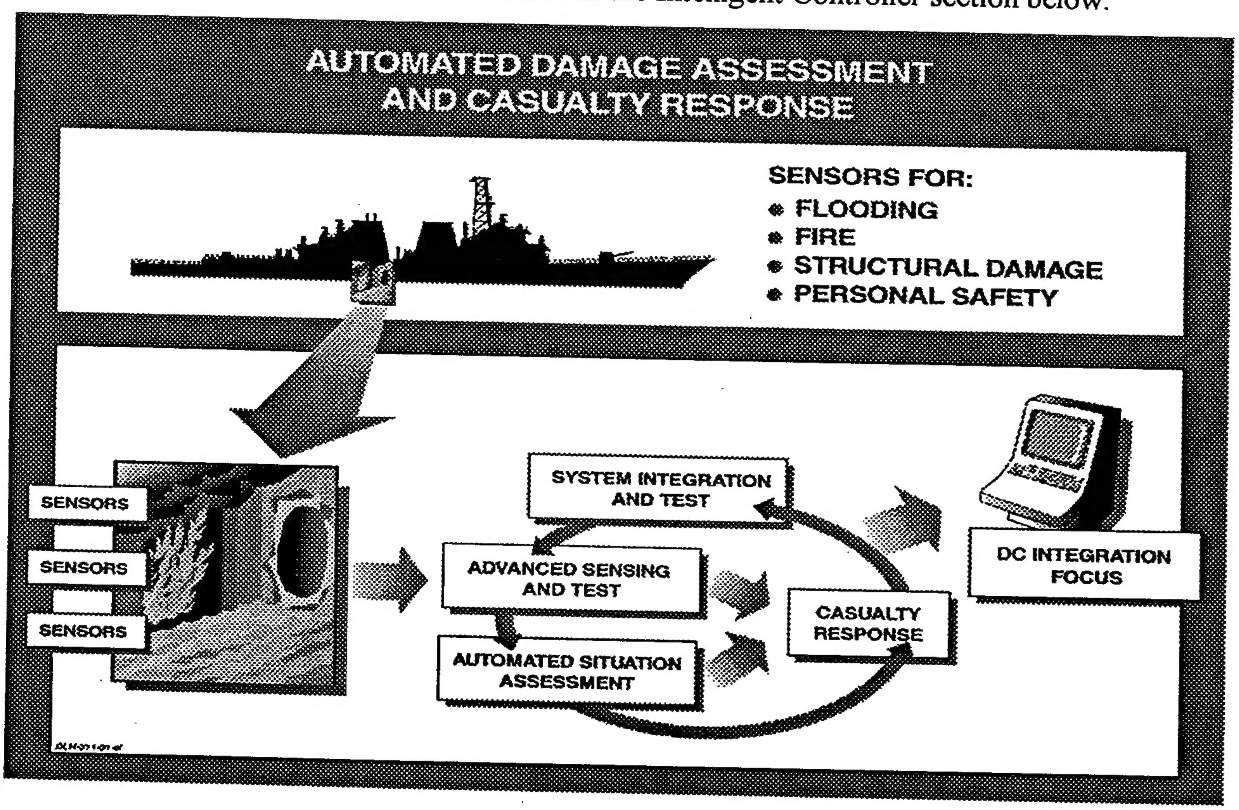


Figure 1. Automated Damage Assessment and Casualty Response

3.3 *Task 3 - Automated Casualty Response*

This task is to develop an automated response capability appropriate for the assessed damage, and represents the autonomous control component that closes the loop in a *detect-assess-respond* sequence. This task also falls under the scope of supervisory control system development. These achievements are also discussed in the Intelligent Controller section below.

3.4 *Task 4 - Systems Integration and Test*

This task provides for linking, testing and performance demonstration of the supervisory control system developed under the scope of the first three tasks. In addition, development of an environmental model, or "emulation", that provides a facility for debugging and testing the supervisory control system as it is developed falls under this task. Also the development of the ARL hardware testbed facility came under this task. Achievements under the first-year's contract for Task 4 are described in the following prototype IC design.

4. THE PROTOTYPE IC: DESIGN AND DEVELOPMENT (Tasks 2, 3, and 4)

4.1 *Overview of Controller Development*

As a subcontractor for this DC-ARM supervisory control project working under the direction of program manager Robert Barr, ARL conducted extensive domain research, including literature surveys, discussions and interviews with damage control experts, and observations of live tests onboard the Naval Research Laboratory's damage control research facility, the ex-USS SHADWELL [1,2]. This accumulation of domain knowledge provided the foundation for design and development of a prototype intelligent controller (IC) based on ARL's intelligent controller technology. The objective of this prototype IC development was to demonstrate the feasibility of automating damage assessment and control for a ship compartment. The IC was designed with a capability to recognize and respond to fire, smoke flooding casualties as well as dangerous temperatures and potentially explosive conditions, and adaptively react to them by generating commands to actuators such as pumps and fire suppression systems. ARL also developed a simple physics-based mathematical model for progression of fire, smoke, and flooding casualties in a compartment as well as for the sensors and actuators installed in the compartment. This model provided a virtual environment to enable development and testing of the IC.

After the prototype IC was developed using the environmental model, it was demonstrated using a testbed facility constructed at ARL that allowed actual smoke, flooding and heat to be introduced. Sensors were installed that could detect smoke, heat and water levels, their outputs used as inputs to analog-to-digital cards. This digitized sensor data served as the input to the IC, which interpreted and reacted to the perceived conditions. The demonstration of the IC operating successfully in this hardware testbed was the conclusion to the first year's DC-ARM supervisory control program.

4.2 *The Environmental Model*

In order to develop an IC for any application, a model or emulation of the physical environment in which the IC will be operating is essential. This environment includes not only a model of the physical world, but also of the components of the "plant" the IC is controlling. These components include the sensing systems that provide input to the IC as well as the subsystems the IC will be commanding. These subsystems enable the IC to effect physical actions in its environment, such as the physical act of applying fire suppression materials. Systems commanded by an IC are generically referred to as "actuators" or "effectors". An emulation of the environment and subsystems enable the designers to iteratively test the IC's closed-loop performance as it is being developed. For this project the environment in question was that of a generic compartment in a ship.

4.3 *Model Development*

The model was developed by creating individual objects, then integrating them into the compartment environment. Some of the objects were very simple and straightforward to develop (such as the water level meter and dewatering pump), while others required more detailed work and research to model accurately (such as the fire object). Where possible, the objects were built using existing relations or equations from physical science texts. If these were not available, relations were developed from analysis of clinical reports. In the absence of given relations or clinical data, an informed estimated calculation was derived for use. Once all the objects were designed, they were integrated into a "compartment object", which is the model used for the physical compartment.

4.4 *Compartment Features*

The environmental model incorporated features of a generic compartment, a set of available casualties, a set of simulated sensors and a set of simulated effectors. The initial casualties available in the model are fire, smoke, flooding and dangerous heat (as would be experienced with a fire in an adjacent compartment). The smoke, flooding and dangerous heat casualties are initiated by specifying some regular input rate to the compartment, be it a mass of smoke, high volume of water or increasing heat energy. A fire casualty is started by specifying a fuel load of class A or B materials, with some exposed surface area and some of that area initially ignited. As a fire proceeds, it may create smoke, dangerous heat or a potentially explosive casualty condition. The last casualty, with potentially explosive conditions, can lead to a fire reflash, backdraft or explosion if not handled correctly by the IC. The sensors provided by the model are a set of three temperature sensors, an obscuration meter, which gives the visual density of smoke in the compartment and a water level meter. In addition, the compartment also includes a hydrocarbon concentration meter, which indicates the concentration of vaporized fuel present in the compartment atmosphere. The effectors in the compartment are a ventilation fan, a dewatering pump, a set of water-mist sprinklers and a set of dampers to open or close the compartment. When a casualty scenario is running, the computer program that runs the model provides a visual representation of the compartment environment. This allows the user to interpret the current state of the compartment and its components.

4.5 The Prototype IC

The design of the IC encompasses two tasks specified in the contract: Task 2, Situation Awareness (Assessment) and Task 3, Casualty Response. An IC built on the ARL intelligent controller architecture has two sub-modules referred to as Perception and Response whose responsibilities closely match these two tasks.

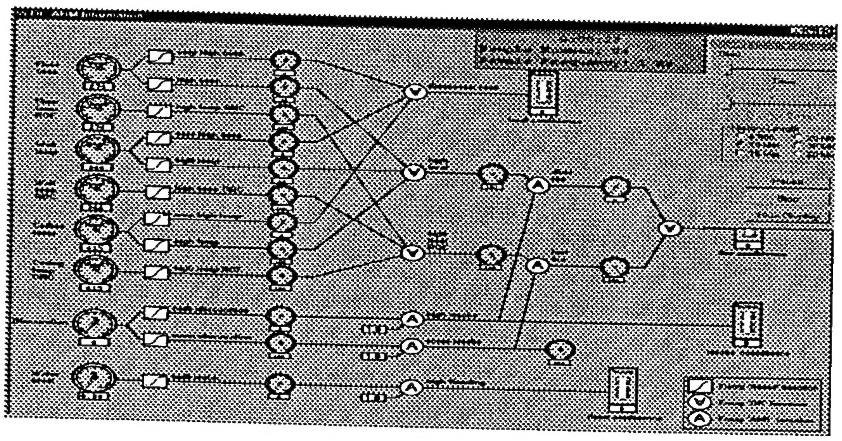
4.6 Scope of Operation

The prototype IC was developed using the ARL IC architecture, its mission being to recognize and respond to a set of casualties within a generic shipboard compartment. These casualties were selected to be fire, smoke, flooding, dangerous temperatures and fuel-rich/oxygen-poor conditions. The controller uses a set of sensors to gather input data. The sensors are of types available on the ex-USS SHADWELL, and represented in the compartment model discussed above. The IC generates a response to a perceived casualty by sending commands to a selected set of effectors. The IC configures these subsystems by specifying control settings such as flow rates and direction as determined by the IC's analysis of response needs for the situation. Effectors are replacements for human muscle and are thus a key factor in achieving a reduction in manning requirements. Assumptions were made as to the type of effectors likely to be deployed on automated ships. For this research and development, the IC was configured to be compatible with effectors expected to be deployed on the ex-USS SHADWELL or human-based approximations of such.

4.7 Casualty Recognition (Task 2)

The prototype IC is comprised of two modules referred to as Perception and Response. Perception is responsible for casualty recognition. It is comprised of two sub-modules, referred to as Data Fusion, and the Continuous Inference Network, or CINET. The Data Fusion module constructs a physical representation of the state of (in this application) the compartment. In the prototype IC design, it calculates smoothed estimates of values in the compartment temperature readings along with their rates of change. The CINET is a multi-stage classifier based on a continuous logic developed at ARL. It provides a capability for designers to represent human expert knowledge related to interpretation of continuously changing data as continuous classification functions in the IC. Details of this approach to automatic feature recognition are contained in Reference 3. The CINET (see Figure 2) for the prototype IC takes as input three temperature readings, three temperature rates of change (from Data Fusion), an obscuration reading, a hydrocarbon density reading and a water level reading. As output, it provides a confidence for the existence of fire, smoke, flooding, dangerous heat and potentially explosive conditions. The output confidences range from 0 to 1, 0 representing "No confidence this property exists", and 1 being "Complete confidence that this property does exists".

Prototype CINET image

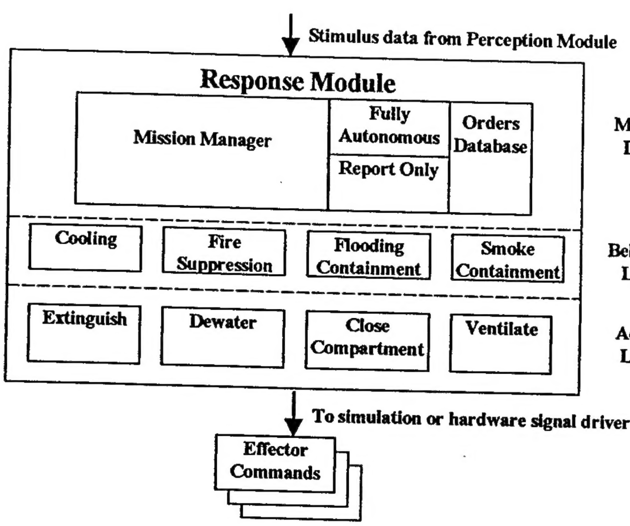


- CINET forms inferences of casualty presence
- Final inferences composed from successive lower level inferences of the existence of physical properties
- Each final inference corresponds to a behavior in response

Figure 2. Casualty Recognition CINET

4.8 Casualty Response (Task 3)

The Response module is responsible for generating and executing a plan to respond to casualties identified by Perception (see Figure 3). Any time one of the output confidences of the CINET is greater than 0, that will trigger a corresponding behavior to request control from Response. The prototype IC has a behavior for each casualty type recognized by Perception; for fire, Fire Suppression, for smoke, Smoke Control, for flooding, Flood Control, for dangerous heat, Cooling, and for potentially explosive conditions, Explosion Prevention. If Perception identifies multiple simultaneous casualties, multiple behaviors will request control.



- Mission Manager selects active behavior dependant on response decision functions, orders from human observer
- Active behavior selects actions to activate to respond to casualty
- Active actions generate effector commands for simulated or real effectors
- Response effectiveness evaluated by goal achievement functions on successive cycles

Figure 3. Response Module.

The prototype IC allows only one behavior to be in control at a given instant. Therefore, the Response module was designed to resolve conflicts between multiple behaviors requesting control. It accomplishes this by using the concept of a "severity rating" for a particular casualty. A severity rating ranges from 0 to 1; a rating of 0 corresponding to a casualty that can be safely ignored indefinitely, and a rating of 1 corresponding to a casualty that demands immediate action to prevent catastrophic damage. As soon as a casualty is identified, the corresponding behavior will generate a severity rating for the casualty. The behavior will continually update that severity rating as long as Perception says the casualty exists. Response will give control to the behavior triggered by the casualty with the highest severity rating. The behavior in control will plan a series of actions to respond to its casualty. These actions will generate orders to configure the effectors available to the controller. At some point, actions taken by the control behavior will cause the severity of the casualty to drop below the level of some other casualty, or Perception will no longer recognize the existence of the casualty. At this point another behavior will be given control, or Response will go to an "All Clear" state. In the future, more advanced versions of the IC will allow multiple, simultaneous behaviors to be executed in real time.

4.9 Supervisor Interaction

The ARL intelligent controller architecture provides for design of systems comprised of multiple ICs under direction of one or more supervisory ICs. For this initial study and feasibility demonstration, only one IC was designed. However, it was developed to operate under human supervision in a way analogous to the way it would interact with a supervisory IC. In general, an IC is responsible for informing its supervisor of its current state and autonomous operations. In return the supervisor may configure priorities of the IC by sending instructions in the form of "orders". The prototype IC responds to one pair of orders from its supervisor: "Automatic Response On" and "Automatic Response Off". When the last order received has been "Automatic Response On", the controller operates in autonomous mode, collecting sensor data, performing situation analysis, plan generation and execution, and then sending a set of commands to effectors. When the latest message is "Automatic Response Off", IC operation is unchanged except that the control signals are not sent. The controller continues to plan and send its supervisor advisories of the casualties it recognizes and of the planned actions it would implement if the signal output were active. In this way, the controller can act as a decision aid even when it is not acting autonomously.

A graphical user interface (GUI) allows a human to act as the controller's supervisor by providing a window to communicate the controller's state, display its advisories and send orders. The GUI displays the controller inputs (sensor data) and outputs (effector commands), the features and confidences developed by the controller's Perception module and provides a text readout of all advisories sent by the Response module. It also provides a supervisor input that allows sending one of the two orders described above.

5. ARL PROOF OF CONCEPT HARDWARE DEMONSTRATION (TASK 4)

5.1 Objective

The primary objective of the DC-ARM Phase I Contract was to prove the concept of the Intelligent Controller (IC) as a viable approach to automation that could eventually be utilized to reduce the sizable manpower requirements in effect in the 1980's-designed ships. With the proven information base provided by the previously discussed research and development effort, a proof-of-concept prototype Intelligent Controller software, PC supported program, was designed for a table top damage control IC demonstration. The application provided for the introduction of blind physical conditions replicating fire (heat), fire-generated smoke and flooding. The PC-supported DC-ARM IC program had a planned capability to detect, measure and assess conditions within a physically contained environment, and then formulate and implement corrective action responses relative to any of the scenario-based conditions occurring that represented a damage control casualty (see Figure 4).

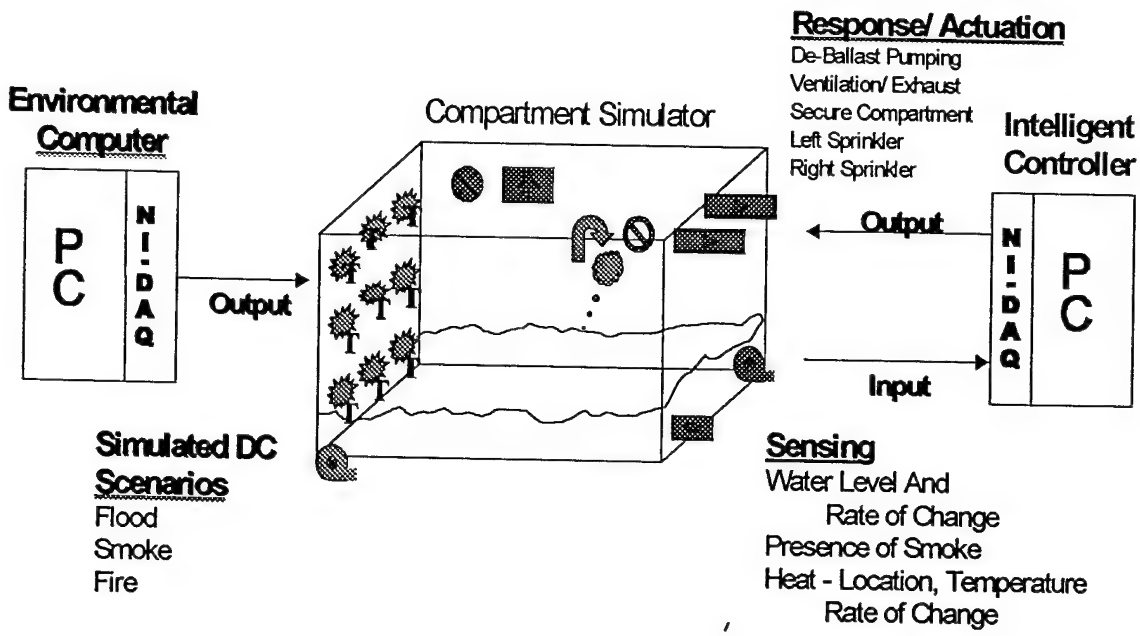


Figure 4. Schematic of Shipboard Compartment and Control System

5.2 Functionality

The conditions within the environmentally contained compartment were detected via nine heat and one smoke detectors calibrated in the IC Program to relate dangerous heat only and provide a confidence factor through a dual sensing photo-electric/ionization smoke detection. Flooding detection was provided by a pressure transducer calibrated on 2" H_2O full scale. The

information provided by the sensors was evaluated through the PC-supported IC Perception module, with the results of that Perception passed on to the Response module. The Response module then generated appropriate casualty management orders to the system actuators in an effort to control unacceptable environmental conditions and return the compartment's condition to normal.

Equipment involved in the demonstration consisted of an environmental computer to simulate flooding, smoke and fire; a transparent box compartment simulator equipped with sensors to detect the water level and rate of level change, a smoke detector, nine thermocouples indicating the heat's location, temperature and rate of temperature change and finally the Intelligent Controller PC. The IC PC received inputs from the sensors and provided activation of de-ballast pumping, exhaust and supply ventilation, closure, and control of left and right water sprinkler systems. Figure 5 is a picture of the (transparent) model constructed to represent a shipboard compartment. Figure 6 depicts both the flooding pressure sensor and operating valve, with the de-ballast valve shown in Figure 7. Figure 8 illustrates the exhaust fan and smoke detector, with the firefighting water spray heads shown in Figure 9.

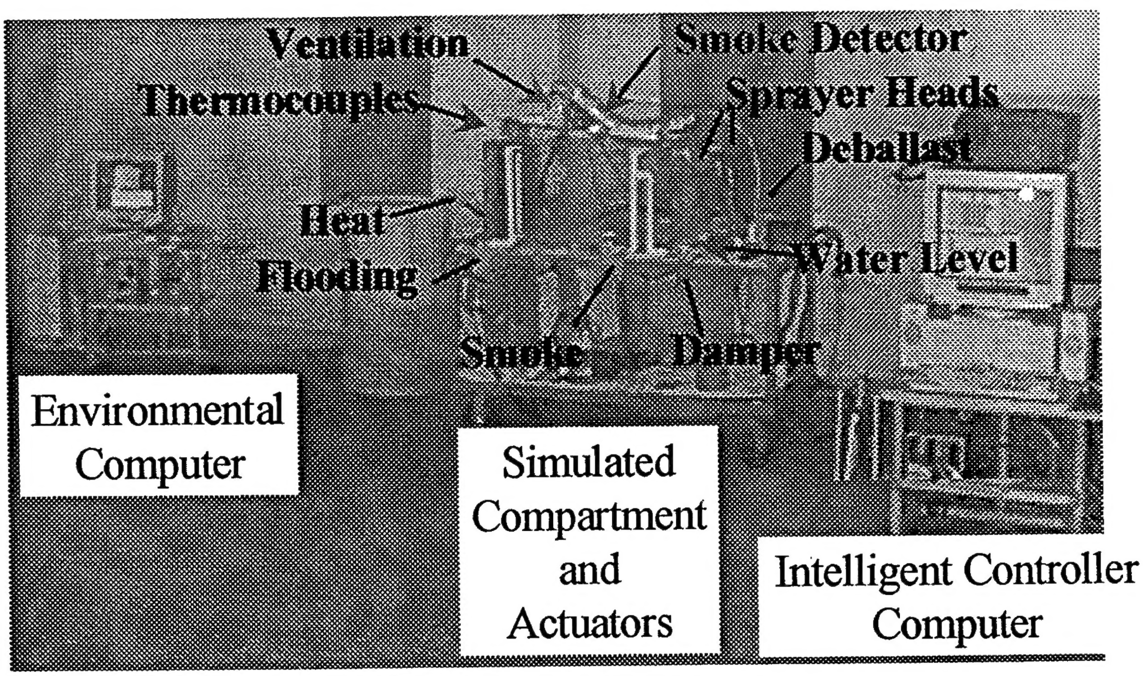


Figure 5. Compartment and Controller Hardware Implementation

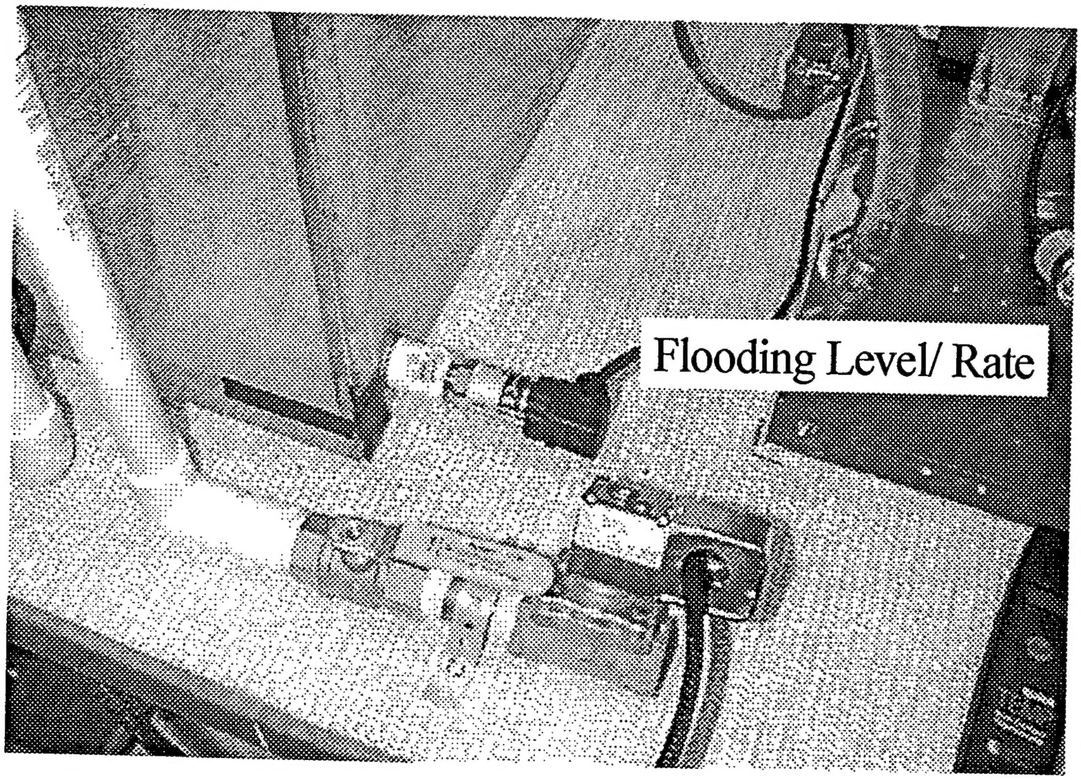


Figure 6. Pressure Sensor--Flooding

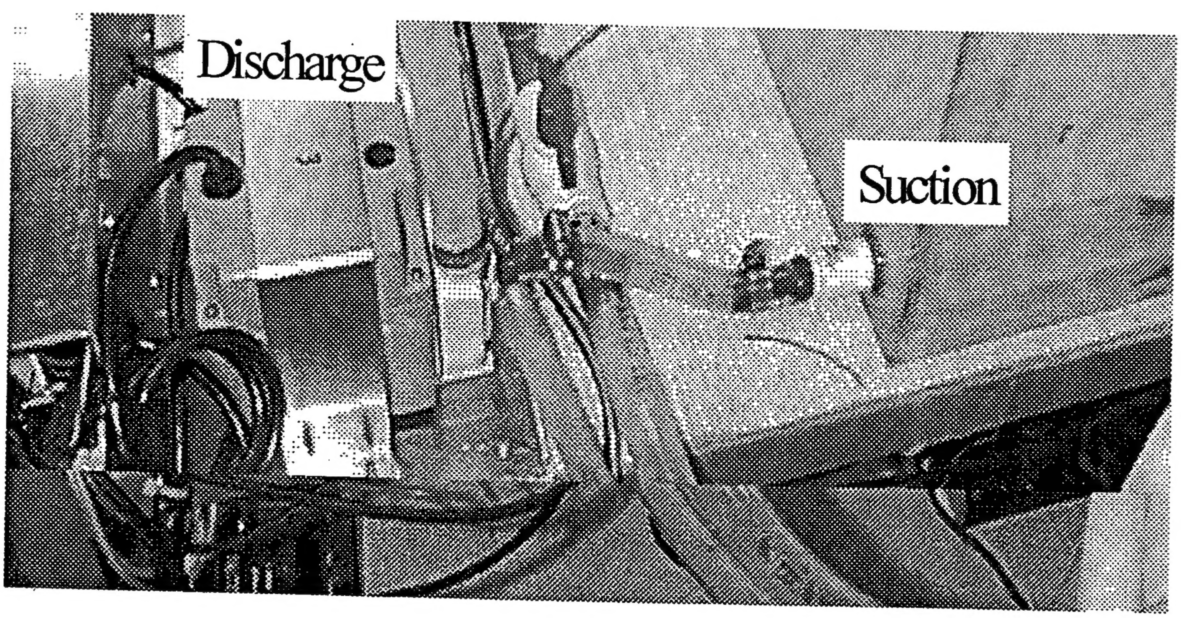


Figure 7. De-ballast Pump

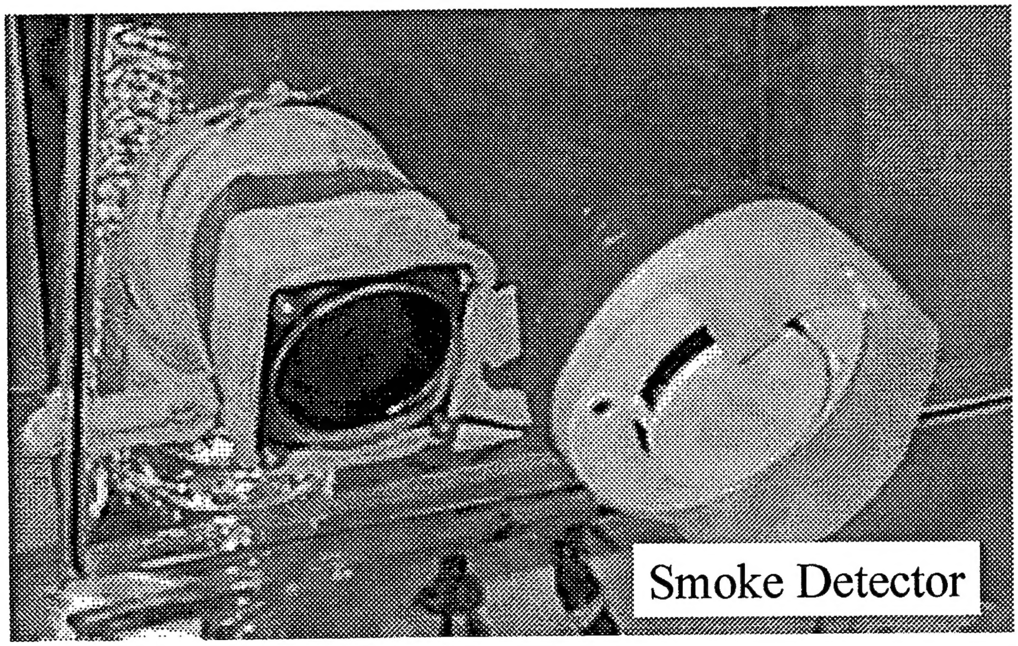


Figure 8. Exhaust Fan and Smoke Detector

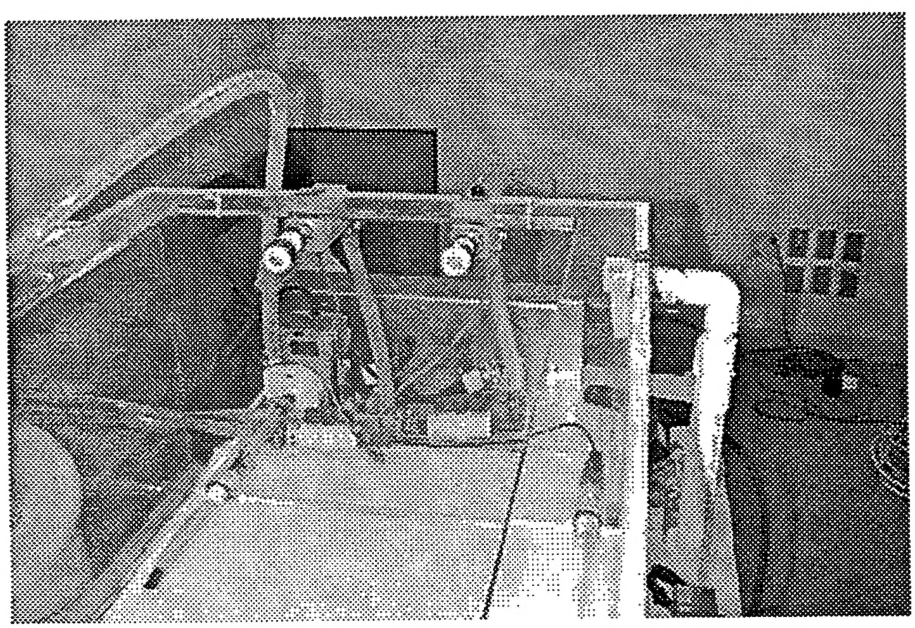


Figure 9. Fire Extinguishing Sprayer Heads

6. CONCLUSION

6.1 IC Demonstration

A demonstration was conducted at ARL on January 6, 1999. During the demonstration personnel from the Navy imposed numerous simulated casualties to evaluate the flexibility and accuracy of the IC prototype. The demonstration was successful in proving the operational concept of automated damage control of smoke, fire and flooding casualties.

7. REFERENCES

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